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INTEGRATION OF PHOTOVOLTAIC UNITS INTO ELECTRIC UTILITY GRIDS:
EXPERIMENT INFORMATION REQUIREMENTS AND SELECTED ISSUES

Executive Summary

September 1980

Work Performed Under Contract No. AC03-79ET30351

The Aerospace Corporation
El Segundo, California

Dist-202
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U.S. Department of Energy

Solar Energy

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**INTEGRATION OF PHOTOVOLTAIC UNITS INTO ELECTRIC UTILITY GRIDS:
EXPERIMENT INFORMATION REQUIREMENTS AND SELECTED ISSUES**

EXECUTIVE SUMMARY

September 1980

**Prepared by
Energy and Resources Division
THE AEROSPACE CORPORATION
El Segundo, California 90245**

**Prepared for
Office of Electric Energy Systems
DEPARTMENT OF ENERGY
Washington, DC 20545**

**Contract No. AC03-79ET30351
Project Agreement 8
Modification No. 7
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ABSTRACT

A number of investigations, including those conducted by The Aerospace Corporation and other contractors, have led to the recognition of technical, economic, and institutional issues relating to the interface between solar electric technologies and electric utility systems. These issues derive from three attributes of solar electric power concepts, including (1) the variability and unpredictability of the solar resources, (2) the dispersed nature of those resources which suggest the deployment of small dispersed power units, and (3) a high initial capital cost coupled with relatively low operating costs. It is imperative that these integration issues be pursued in parallel with the development of each technology, if the nation's electric utility systems are to effectively utilize these technologies in the near to intermediate term.

An important part of the DOE programs to develop new source technologies, in particular photovoltaic systems, is the experimental testing of complete or nearly complete power units. These experiments provide an opportunity to examine operational and integration issues which must be understood before widespread commercial deployment of these technologies can be achieved. Experiments may also be required to explicitly examine integration, operational, and control aspects of single and multiple new source technology power units within a utility system. An identification of utility information requirements, a review of planned experiments, and a preliminary determination of additional experimental needs and opportunities are presented in Part I of this report.

From the many other issues that are of concern in the integration of photovoltaic solar energy units into electric utility grids, several relative to on-site systems have been selected for further discussion and analysis:

- The impacts of on-site photovoltaic units on load duration curves and optimal generation mixes are considered.
- The impacts of on-site photovoltaic units on utility production costs, with and without dedicated storage and with and without sellback, are analyzed.
- Current utility rate structure experiments, rationales, policies, practices, and plans are reviewed.

FOREWORD

The work described here was performed by The Aerospace Corporation under contract to the San Francisco Operations Office for the Office of Electric Energy Systems of the Department of Energy (Project Agreement 8, Modification No. 7 of Contract DE-AT03-79ET30351). This work covers a performance period from May 1979 through December 1979. The objective of this study was to identify and analyze selected issues of concern in the integration of photovoltaic systems into electric utility grids. The purpose of this report is to present in executive summary form investigations of three of these issues in self contained parts as indicated below:

- Part I. Experiment Information Requirements
- Part II. Generation Mix and Cost of Production Impacts
- Part III. Rate Structures for On-Site Photovoltaic Units

A more detailed version of this report is also available.

ACKNOWLEDGMENTS

Part I, Experiment Information Requirements, of this report was written by Drs. Ted Davey and Richard Rountree and was based on analyses and interviews conducted by them and a utility consultant, Mr. James Beck. The material in Part II, Generation Mix and Cost of Production Impacts, was generated and prepared by two authors. Dr. Davey was responsible for the discussion on generation mix impact, and Dr. William Dickter was responsible for the discussion on fuel savings impact. The rate structure survey material, Part III, represents the work of Dr. Lawrence Schelhorse and Mr. Leon Bush and was written by Mr. Bush. Program management and documentation overview were provided by Drs. Mason Watson and Keith Cretcher.

The patient and extensive support in preparing the text and many of the tables and figures from Micki Lewis, Chriss Gamez, and Ginny Jackson is gratefully acknowledged. Appreciation is also extended to Mr. Fred Eggers for art and publications coordination.

PREFACE

A number of investigations, including those conducted by The Aerospace Corporation and other contractors, have led to the recognition of technical, economic, and institutional issues relating to the interface between solar electric technologies and electric utility systems. These issues derive from three attributes of solar electric power concepts, including (1) the variability and unpredictability of the solar resources, (2) the dispersed nature of those resources which suggests the feasible deployment of small dispersed power units, and (3) a high initial capital cost coupled with relatively low operating costs. It is imperative that these integration issues be pursued in parallel with the development of each technology if the nation's electric utility systems are to effectively utilize these technologies in the near to intermediate term. The purpose of this report is to document investigations of three of these issues: utility information requirements, generation mix and production cost impacts, and rate structures in the context of photovoltaic units integrated into the utility system.

Utility Information Requirements

Although it is not clear whether on-site PV units will be owned or operated entirely or partly by utilities, it is certain that widespread near term deployment of PV units will require a utility interconnection. This interconnection will require utilities to develop an understanding of PV units, their operation, and the effective integration of these units with the grid. To acquire this knowledge and experience, a number of experiments are to be conducted which should include utility participation. The specific utility information requirements to be met by these experiments must be examined to properly define the experimental program. The analysis of this issue is covered in Part I of this report.

Generation Mix and Production Cost Impacts

The introduction of significant numbers of PV units into the electric utility grid will affect utility generation costs through fuel savings, potential changes in the mix of

future generation capacity to minimize production costs, changes in the operation of the system, and potential reductions in system capacity requirements allowing postponements in installation or even cancellation of planned generating units.

Critical to determining the economic impact of PV units is the consideration of sellback of excess solar energy from on-site locations. On days of high insolation or low load, there could be a significant amount of such excess energy. Equally important to the analysis is whether there is dedicated on-site storage for accumulating excess energy during the day to meet the on-site nighttime demand. The benefits of PV storage or sellback, or a combination of these capabilities, will depend on the point of view taken: the utility, the customer, or the aggregate, and on the rate structure. A detailed analysis of these considerations is presented in Part II of this report.

Rate Structures

The electricity rate structures established for backup and sellback associated with PV units are of primary importance in determining both utility and customer economics. Such rate structures can either encourage or discourage the implementation of PV units. The practices, policies, rationales, experiments and plans of electric utilities, relative to PV or any solar parallel generation, are of definite interest and presently unresolved. The discussion of this issue is presented in Part III of this report.

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PART I. EXPERIMENT INFORMATION REQUIREMENTS

1.0 INTRODUCTION

The major contribution of this part of the study is the comparison of the informational contents of the major photovoltaic (PV) unit experiments with the informational requirements imposed by electric utility companies who are facing PV decision opportunities. The outcomes of the comparison are reported in the form of recommendations for modifications and additions to existing experiments, for the formation of an information transmittal format for communication with utility companies, and for augmentation of the national PV experiment program.

The conclusions drawn in this report are preliminary, and greater clarity of the issues will develop as the utility companies themselves devote more attention to the natures and weights of the impacts associated with PV implementation.

The overall purpose of the study task is to support the utility implementation decision process through identifying and defining utility information requirements and through characterizing the information potentially available in the national experiment program as it is presently conceived by the Photovoltaic Division of DOE (DOE-PV). The realization of the purpose is approached through the accomplishment of the following four specific task objectives:

1. Identify the information which will be required by electric utilities in making decisions regarding the integration of on-site photovoltaic systems.
2. Determine the extent to which the pertinent information will actually be obtained in the course of photovoltaic experiments and system demonstrations.
3. Identify gaps or discrepancies between the information required and the information to be actually obtained.
4. Recommend alterations of and/or additions to the national program of experiments and demonstrations.

It is clear that the goal of accelerated commercialization of PV supports the top level national purpose of energy sufficiency through both conservation and production contributions. The conservation contribution arises from a fuel use replacement effect and results in a view of PV, especially in on-site applications, as a load modification. The production contribution arises from the view of PV as an additional energy generator. To support the utility decision process, information is needed and a primary source of such information is the DOE-PV experiment program.

It is important to realize that while the commercialization goal is definitely supported by the development of PV technology, an ongoing activity for several years, it is also necessary that the stage be set for system implementation by thoroughly satisfying the needs of the electric utility companies within whose supply networks such systems will be built.

2.0 STUDY APPROACH

The first step in identifying the utility information requirements was the creation of an Aerospace in-house hierarchy of utility concerns. The hierarchy was created through a process of identifying issues which, if resolved, would support resolution of an issue at the next higher level. In this sort of hierarchical analysis there is a gradual shift from broad and wide ranging concepts near the top of the hierarchy, through more sharply defined activities in the middle, to detailed requirements at the bottom. From the experiment information requirements point of view, the analysis process terminates when the branches in the hierarchy end in the definition of actual variables to be sensed, recorded, and processed in an experiment. This report provides relevant information through middle level requirements.

The preliminary Aerospace analysis was taken into the field and exposed to several groups of utility personnel. A background briefing was presented at each utility company visited, followed by extensive round tables on the issues as appreciated by that particular utility. The utility companies visited then agreed to continue on their own with in-house analyses of the issues using the Aerospace-derived requirements as a structure, and to communicate the results to Aerospace when available. Finally, the Aerospace study team interpreted the discussions from a composite utility viewpoint.

Next, the availability and suitability of the utility-required information within the context of the presently defined DOE-PV experiment program were investigated. The task activity involved assessing the scope of the information content expected from the presently planned experiments and translating this information into a form convenient for comparison with the utility requirements.

The gap analysis, which is the term used to refer to the process in which gaps or discrepancies in the informational content of experiments from the utility point of view are identified, consists of a comparison between the information which is needed and the information which will be available and suitable as a result of the experiment process.

3.0 IDENTIFICATION OF CRITICAL UTILITY INFORMATION REQUIREMENTS

The identification of critical utility information requirements was initiated by Aerospace with an in-house analysis based on prior PV experience and previous utility interactions. This information base was expanded with a literature search, and by conducting a preliminary utility field visit with Southern California Edison Company (SCE) personnel. The expanded set of information requirements was categorized according to five major PV question areas facing utility decision-makers. The five question areas span the utility/PV issues of:

- Grid Integration
- Economic Impact
- PV Technology
- Social/Institutional
- Equipment Supply

Seven utility field visits were made including the early coordination meeting with SCE. Aerospace structured the visits as information brainstorming sessions posing Aerospace as an effective communication channel to DOE from the utilities.

The preliminary set of utility information requirements identified to date are based on the messages obtained from the technical interchanges accomplished during each field visit, on the utility consultant's recommendations, and on the Aerospace experience and literature search.

Several basic messages regarding PV implementation in utility grids received by Aerospace during the utility field visits are summarized below. The comments represent a consensus of utility opinion, although some variations of emphasis naturally occurred. An interesting sidelight is that the utilities appeared enthusiastically interested in participating, since they felt the activities served to better prepare them for forthcoming similar investigations of other new energy source evaluations.

Rankings of the concerns of the utilities indicate that grid integration issues are of paramount importance in utility considerations, followed closely by economics

and technical performance. However a time phased perspective of these issues, as indicated in Section 4.0, indicates a degree of reversal. Experiments addressing technical performance need to be accomplished first in order to answer some of the critical grid integration questions. Furthermore, economic verification will depend on hard cost data, which will come out of actual experience.

An important result of the study is the identification of a number of specific areas in which utilities have indicated a crucial need for PV experiment information:

- **Safety of Personnel**

- Identification of hazard areas and activities
- Techniques for system disconnection, interlocks, etc.
- Training levels required for safety in maintenance
- Structural and support loading measurements, environment

- **System Protection**

- PV impacts on power quality, network stability
- Power conditioner performance effects
- Tests of control equipment
- Identification of network control and switching operation impacts
- Synchronization experience

- **Load Management**

- Hardware performance characteristics
- Load management logic and implementation
- Identification of appropriate loads
- Load management accommodation of PV impacts

- **Economics**

- System and installation cost data for extrapolation
- Maintenance and other operating cost information
- Elasticity of PV demand with seilback rates
- Preferential rate structures
- Hidden costs due to grid integration
- Local perturbations (environments, costs, etc.)
- Implementation impacts on utility financial well-being

- **Customer Attitudes**

- Maintenance logs documenting service calls and resolutions
- Tolerance to resident system
- Aesthetic considerations

- **System Lifetime/Reliability**
 - Long-term data
 - Failure modes and intervals
 - Performance trend analyses, deterioration
 - Warranties
- **Capacity Credit**
 - Loss of load measurements
- **Legal/Jurisdictional**
 - Liability for system damage and bodily injury
 - Ownership
 - Insurability
 - Service access
 - Rate base
- **Market**
 - Rates of penetration
 - Rate structure tolerance
 - Incentive efficacy
- **Preferred Systems**
 - Qualification procedures for suppliers, installers, servicers
 - Degree of public reliance on local utility recommendations
 - Optimum configurations (flat, concentrator, storage, etc.)
 - Availability
- **Demand Profile Data**
 - Periodic sampling for utility analyses
- **Grid Connection**
 - Methods and designs for connection
 - Required network modifications
 - Equipment problems
- **Training**
 - Methods and materials
 - Minimum levels acceptable
- **Maintenance**
 - Technical system performance as function of maintenance levels
 - Maintenance requirements on systems
 - Recurring fault areas

4.0 ANALYSIS OF EXPERIMENT INFORMATION CONTENT

An analysis of the information flow within the DOE-PV experiment program was performed to determine the extent to which pertinent information is expected to be obtained from current and planned photovoltaic experiments and demonstrations. Plans for the DOE-PV experiments, for example, the Intermediate Load Center experiments conducted under PRDA 35/38, have placed a high degree of emphasis on the development of information requirements. The study summarized here included detailed examinations of requirements and plans which are reported in the main study report volume. The most significant observations from this effort pertain to the perceived position of the utilities among data users.

It is pertinent that the utility community is perceived as one of a group of many users. This perception does not fully exploit the greater spatial and temporal extent of the utilities as common participants in many individual projects during each program phase and through several phases of the program from initial experimentation through commercialization. Further assessment of experimental information flow and formatting may increase the effective use of the unique position enjoyed by the utilities by which they can obtain the maximum transfer of data from project to project. Data transfer between parallel or similar projects is important during each development phase and also between projects that are sequentially related across the several development phases, e.g., Initial System Evolution Experiments through Commercial Readiness Demonstrations.

5.0 ANALYSIS OF GAPS BETWEEN UTILITY/DOE-PV INFORMATION CRITERIA

A summary of the apparently different philosophical positions held by the utilities and DOE-PV provides the first stage of the gap analysis. The gaps identified in this section serve as the source of specific recommendations regarding the experiment program.

Anticipation for the Commercial Readiness of PV. The utilities view commercial readiness as being in the distant future, if at all, and must retain their current commitments for expanding generation mixes over 10 years in the future. They share an experienced uncertainty regarding actual lifetime of any new technology. Conversely, DOE-PV anticipates readiness for the residential and ILC applications by the mid-1980s, based on its studies and developments to date. DOE-PV will rely on reliability being established along the way and on accelerated aging tests.

Means for Progressing to Potential Commercial Readiness. The utilities want a sequential evolutionary process with proven feasibility carried along at each step. The utility community would prefer to rely on a few well conceived experiments with appropriate funding for each. The basic concept of the DOE-PV approach is similar in that an evolutionary process is intended, but a difference exists in the implementation by DOE-PV. This difference involves parallel activities and sequential equipment development in order to accomplish the mid-1980 readiness, without anticipation of failure.

Degree of Realism to be Incorporated in the Experiments. Utilities are concerned about customer reactions, safety in servicing, unexpected load changes, and other factors. They feel that meaningfully high levels of power must be involved to ascertain the true influence on their grid networks; higher levels would require higher funding for the experiment involved. Contrasting the higher levels of power sought by utilities, the existing plan calls for lower levels at multiple experiment sites as the pattern for using available funds.

Impacts Associated with Grid Connection. The utilities are uncertain about the impact of PV on the operation of their grids, on grid security, in terms of protecting controllability and stability, and on the safety of people involved in installing, operating, and maintaining the equipment. A key factor in their consideration is adequate training for those involved in such activities. Again, DOE-PV indicates interest in most of these issues, although it feels grid backup is forthcoming with proper utility arrangements. Grid impact is expected to be determined by data evaluation corresponding to the series of system experiments, but very little appears in DOE-PV literature regarding training requirements.

Degree of Awareness that Exists Concerning the Planned DOE-PV Program. The utilities have expressed concern about the apparent lack of planning, logic, coordination, and priorities in the program. However, the Multi-Year Program Plan (MYPP) addresses such issues, and the forthcoming User Requirements report addresses data requirements for the critical system experiments. Expediting draft coordination and document release would alleviate a substantial amount of this concern.

Attitude of Underlying Caution Among the Utilities. Such caution seems to be due to a feeling of a lack of realism in an accelerating program being conducted independent of their involvement. However, the program does place some emphasis on actual user environment, and DOE-PV interacts with utilities by using utility representatives (e.g., individuals, EPRI) as advisors, as eventual users of the experiments data, and as PRDA associates.

General Need for Utility-Specific Information Requirements to be Adequately Addressed. Utilities are highly concerned about their service areas and local regions, and would like information extrapolated for use in their local analysis activities. Such a requirement would have to be built into the program early. In contrast, DOE-PV essentially views the utilities as a group and as one of many user groups interested in the experiment data, which would therefore be privy to the general data bank to be provided by DOE-PV to all user groups.

Ownership and Control of PV Units. The scope of this utility concern comprises responsibility for such activities as operation and maintenance, associated basic training, warranties, and personnel safety. Very little has appeared in the DOE-PV literature to date on this issue, but implied responsibility would exist with the public in the residential/Intermediate Load Center (ILC) applications, and with the utilities in the central stations. An early resolution of this issue is essential for the smooth integration of PV into utility scenarios.

Central Station vs Distributed Applications. The utilities would prefer a resolution via early well conceived experiments comparing each approach. DOE-PV has adopted the residential/ILC applications as being highly probable for early commercial readiness, with central station perhaps following in the future. Several utilities point out that large, centralized plants have historically always won in the economics tradeoff.

Sellback of Excess Energy Generation. The impact and role of the various candidate approaches, relative to potential capacity credit, is part of the resolution to be accomplished. DOE-PV presently relies on study results, preferring sellback over the apparently more expensive storage options, and will gather data on the subject during planned experiments.

Degree of Experiment Flexibility. Utilities indicate an inclination toward incorporating modularity in a few early and on-going established experiments, thereby allowing adoption of advanced technology breakthroughs as they occur. The PV program is planned to incorporate such breakthroughs in some of the multiple experiments to be subsequently initiated.

Availability of Complete PV Experiment Program Documentation for the Utilities. This includes test and evaluation plans, progress reports, and individual and composite experiment final results, including such data as preferred systems and qualified suppliers. Present DOE-PV intentions are to provide the utility data according to their user priorities, to provide the general PV data bank, and to issue appropriate specifications and standards.

Utility Involvement and Active Participation. The utilities indicated a desire to participate, but they appeared to be more sensitive to their own service areas or local regions, and to well conceived experiments designed to meet their own needs and interests. Currently, DOE-PV relies on utilities as advisors, eventual users of experiment data, and as PRDA associates.

Increase in Interest Concerning Utility Demand Control Options. The interest in options such as load management and storage is increasing due to the effects of photovoltaic energy on the utility load profiles and on the consequent daily planning for generation. The current DOE-PV program does not appear to address these issues together, so experiments providing information on the viable combinations of these factors need to be defined.

Completeness of Information Categories Created by Aerospace. The utility field visit results indicate that they were essentially complete, but that the priorities assigned to each should be time phased. Comparison to the DOE-PV data requirements indicates that the six requirements categories match those of the PV Test and Applications (T&A) program activities, but time phasing pertains to a different categorization of the same information.

A review of the comparisons made indicates that there are a few significant gaps in philosophy. Some issues recur for more than one of the comparison interpretation viewpoints, but there is a much smaller overall gap existing than is generally recognized by the utilities. For example, both communities are highly concerned about real-world problems, evolving into commercial readiness, and developing a well structured program plan to carry out the evolution. Many of the gaps are matters of degree of different preferences rather than basic polarities, and can be remedied with minor modifications and additions to the DOE-PV program.

Basic and recurring gaps were determined to be associated with the following:

- Longer test periods are needed to establish reliability and commercial readiness.
- Utility communication and participation activities need to be initiated and emphasized.
- Greater concentration of program resources on a few experiments is needed.
- Greater emphasis is needed on resolving system ownership and jurisdictional concerns.
- Mutual awareness of problems and progress is needed by utilities and DOE.
- Approaches are needed for interpreting results of distant experiments to local applications.
- Greater emphasis is needed on quantifying grid integration impacts on utility operation.
- Central station application needs greater attention.
- Load management effects in the presence of solar generation need study.

6.0 OBSERVATIONS AND RECOMMENDATIONS

OBSERVATIONS

Several observations were made during the course of the study which are not actually results or conclusions of the analysis effort. Instead, they represent attitudes and experiences which are judged to be significant either because of their ubiquity among the utility companies or because of their potentially pivotal effect on the course of alternative energy generation developments.

It is emphasized that these observations are the study team's interpretations of its experiences and of utility-held attitudes. Therefore, the observations do not necessarily represent positions held either by the Aerospace team or by every utility visited, nor do they constitute specific recommendations for DOE action. They are reported for their information value.

Furthermore, despite the apparently wide gap implied by some of the observations given below, the gap analysis conducted for this study yields two supplemental observations:

- Informational and approach gaps between identified utility requirements and planned experiments are not as wide as implied by some of these perceptions.
- Recommendations can be made to minimize gaps that do exist, and these are offered for consideration in the final section.

Utility Attitudes Toward Government Activities: The utility companies visited varied somewhat in the expressions of their attitudes toward the roles government agencies, particularly DOE, are taking in the PV development activities. However, there were some common themes heard more or less loudly at nearly all the utility companies.

There is a general feeling that government is too eager to get to the marketplace with the alternative energy systems and that insufficient time and experience are being devoted to the demonstration of commercial readiness. The vision is of huge government expenditures to create what may be an artificial market, which

will collapse into the tremendous vacuum left by government's withdrawal of support after victory has been declared. A related concern is that the market will be seriously damaged by disenchantment with devices which have not been thoughtfully and carefully tested over long periods of time. Several groups illustrated their concern in this area with examples from the solar heating and cooling experience.

Other feelings in this category expressed by the utilities included:

- Political considerations are being allowed to contaminate technical decisions regarding PV experiment planning, with the result that information content is seriously degraded for all the experiments.
- The inconstant and possibly ephemeral nature of government incentives programs renders long term planning for PV an exercise in guesswork.
- The transience of DOE personnel creates severe disruptions in government funded programs.
- There is a tendency to see DOE as a monolithic entity, without clear distinction between the organizations and purposes of the Photovoltaic Division and the Office of Electric Energy Systems.

Utility Perceptions of PV Imminency: There is a general consensus that photovoltaic energy conversion is an exotic technology and that any meaningful penetration of the energy supply by PV is in the distant future, even in utility planning units of time. The earliest estimate for a central station installation was 1990, and this was viewed as a very small experimental plant.

Status of Utility Awareness of PV Impacts: Due partly to the nonimminence of PV implementation and partly to the typical work pressure on utility technical staff personnel, the depth of detailed analysis regarding PV impacts already performed by utilities was in general not sufficient to allow real-time discussion of the detailed information requirements in the meetings. It was not possible to penetrate to a detailed level, that is, to the actual data requirements. However, all of the utilities expressed a willingness to use the hierarchy charts as a structure within which to

perform additional review and analysis on their own. It was also not possible to get a clear statement of information requirement priorities (i.e., "What really needs to be known first?") beyond the first hierarchical level.

The Aerospace study team came away from some of the meetings with a qualitative impression that many utility companies could be much better informed regarding DOE programs, in particular the PV Multi-Year Program Plan and the activities of the PV Data System Task Team being organized within the PV Program by Jet Propulsion Laboratory. On the other hand, the companies feel they are not adequately included in the PV Program, and that they are not being consulted extensively enough regarding the requirements they have and the constraints on their operational choices.

Utility Positions on PV Experiment Programs: The utility companies generally agreed that many of their information requirements could be satisfied by experiments involving other utilities, and uniformly expressed a preference for a program which sponsors a few very well conceived and implemented experiments rather than a plethora of limited ones patterned after what several termed a "scattergun" approach. In general, they are desirous of participating in experiment design and in monitoring the course of experiments in other utilities. With respect to experiments in which they are the host utility, there was a desire for funding flexibility to allow the introduction of the latest technology equipment.

With respect to PV lifetime qualification testing, a very high priority requirement with all the companies, there was considerable doubt surrounding the value of accelerated life testing. The attitude was that accelerated testing serves as an indicator, but no hard generation planning decisions can be based on it. The minimum actual life test duration for credibility with the utilities was given as five years, and the utilities stressed that the testing had to be performed under local environmental conditions.

Utility Positions on Selected Technical Issues: Utility perceptions on three specific technical issues are included here due to the widespread interest in them. The issues are:

- The degree to which capacity credit, if any, can be earned by PV
- The appropriate position to take regarding excess energy sellback
- The central station versus on-site applications question

With respect to capacity credit, very few of the generation planning people involved in the meetings felt that capacity credit would be earned by PV. In general, they recognized that this position contradicts analysis results based on loss-of-load probability considerations, and gave as justification the presence of evening demand peaks, weather outages, and the practical limits of energy storage.

The companies generally expressed uncertainty with regard to the best approach to determining sellback policies and rates. It is recognized that sellback energy can have serious effects on generation operations, and that it may be economically justifiable, though possibly precluded by public utility commission actions, to charge the customer with on-site photovoltaic generation a higher rate for backup energy than his nonsolar neighbor.

Several of the utilities perceive that a major decision has been made favoring on-site applications over central stations. They argue that the utility industry exhibits a long history of economy-of-scale success and that it is too early to make any irreversible decisions.

Utility Reception of the Aerospace Information Requirements Mission: The utility companies were uniformly cooperative in establishing the visits, and exhibited considerable energy in supporting the Aerospace mission. Personnel from many areas of each company were committed to the meetings for their duration, usually 4-5 hours, and there was a strong interest in expressing their positions, utilizing the study team's role as a communication channel with DOE.

It was also noticed that the discussions and the requirements hierarchies left with the companies served an unforeseen purpose as a stimulus to their own thinking and as a structure within which to pursue in-house analysis of their information requirements.

With respect to the information requirements identified, the following sets of recommendations are advanced to promote the satisfaction of the crucial utility information requirements. Some recommendations relate to activities already planned for accomplishment by DOE-PV, and in such cases the intent here is to reinforce those steps. Some of the others are directed at the strategies to be implemented by the Office of Electric Energy Systems (DOE-EES).

RECOMMENDATIONS

The recommendations based on study findings are of three distinct types. The first adheres strictly to the purpose of the study and suggests modifications or additions to the photovoltaic experiments in the current catalog. The second type of recommendation addresses the form and function of information transmittal to the utility company for its decision-making activities. Finally, the third type of recommendation addresses some of the broader issues which surfaced in the Aerospace contacts with the utility companies, and which can be described as policy recommendations.

Experiment Modifications and Additions

Power Levels (DOE-EES): Select at least one experiment for which the photovoltaic power produced exceeds demand in an isolatable branch of the energy distribution system to allow measurements to be accumulated in a sellback regime.

Grid Interaction (DOE-EES): Develop and incorporate procedures and supporting equipment for rapid location, isolation, and removal and repair of failed PV units, and document associated findings.

Technical Performance (DOE-PV/EES): (1) Ensure that data are collected to yield key sensitivities such as the dependence of PV structure costs on environmental differences, or network performance as a function of PV/grid dynamic parameters; (2) acquire data to identify both operational and non-operational characteristics of the inverters: i.e., power quality, VAR requirements, and quiescent role as a load.

Load Management (DOE-EES): Include an experiment to investigate realistic load management options coupled with PV energy generation.

Duration (DOE-PV): Identify an early experiment to demonstrate a minimum PV five year lifetime. Utility acceptance of commercial readiness cannot be assumed until at least that point is reached.

Installation, Operation, Maintenance (DOE-PV): (1) Provide descriptive material documenting installation procedure experience, including mistakes and blind alleys; (2) design and incorporate service forms for use in logging customer telephone calls - nature of service request and resolution; (3) determine training requirements and procedures that are necessary for operation in the various spatial scenarios, and provide corresponding documentation including training materials and films.

Customer Interactions (DOE-EES): (1) Establish test educational programs, such as short courses for utility planning personnel to aid in monitoring PV experiments and readying for subsequent penetration; (2) supplement one or two experiments with the sampling of attitudes, reactions, and various market forces.

Information Transmittal

User Requirements: Each experiment should incorporate and satisfy the user requirements identified in the DOE-PV Data System Task Team activity.

Data Planning: Ensure that data will be available to the utilities from each experiment stage, from component development through the Commercial Readiness Demonstration Programs, and assess how Test and Applications information will be used in Commercial Readiness Demonstration Program activities.

Reduced Raw Data: Since all data forthcoming from the DOE-PV data bank will apparently be already reduced, it is crucial to identify the parameters of interest (e.g., sensitivities) or make raw data available to utilities.

Utility Functions: Consider categorizing end-use, experiment information along utility functional lines such as generation, operations, service, billing, transmission, and distribution to facilitate use within the utility.

Before and After PV: Ensure availability of pre-project data, to obtain before and after assessments.

DOE-PV/EES Policies

Utility Involvement: Expand the participation level of and general consideration accorded to utility company personnel in the national photovoltaics program. Ways to accomplish this include (1) formation of a DOE-PV/EES/Utility Information Working Group; and (2) elevating utility status from one of many user groups to a separate participating interest group.

Working Group Charter: Adopt a Utility Information Working Group charter to: (1) include creation of a Multi-Year Program Plan for Information (MYPPD) which parallels the present version of the DOE-PV program MYPP, includes the goals and strategies anticipated by DOE, and thereby links the temporal phases of PV development together; (2) incorporate information requirements and findings coordinated with the various utility experiments that are being cataloged and monitored by EPRI; (3) expand the PV Data System Task Team activities in the T&A area using the team as a subcommittee.

MYPP Release: Coordinate MYPP upgradings with the working group, thereby facilitating utility awareness of the national photovoltaics program. Create an MYPP tutorial document for easy assimilation by utilities, and institute a mechanism for utility feedback.

PV Data System Task Team Activities: Renew emphasis on and provide funding for the team activities to ensure the incorporation of identified user requirements into data parameters and functional requirements throughout the PV experiment program.

Program Emphasis: Increase emphasis on central station applications and establish a focussed central station responsibility. Define commercial readiness to include utility decision process with respect to PV lifetime and reliability.

PART II. GENERATION MIX AND COST OF PRODUCTION IMPACTS

1.0 INTRODUCTION

Due to the cyclic and occasionally intermittent character of on-site photovoltaic generation, most applications involving significant penetration of the on-site load will require the availability of backup energy from the utility company through some form of grid connection. The existence of a connection with the grid opens the possibility of reverse energy flow, termed sellback, during periods in which the photovoltaic generation exceeds the demand of the local load. Both these energy flows, backup and sellback, create perturbations in the utility demand profile and have corresponding impacts on the optimum generation mix, the capacity factors of the various conventional generating units, and the resulting costs of energy production.

It is the objective of the task summarized in this section to quantify these impacts, and to analyze their sensitivity to changes in such variables as solar penetration of the on-site load, photovoltaic array size, insolation levels, conventional plant generating mix, and others.

A fundamental property of photovoltaic systems is that, although the fuel is free, the conversion equipment is expensive relative to customary utility operation. Thus the adoption of on-site photovoltaic units may require a shift in the payback periods required by owners as a criterion for making capital expenditures. Also a factor concerning fuel price as an analysis parameter is its differential rate of price escalation. This is a quantity of great uncertainty in analyses of future scenarios. Given the situation with respect to foreign control of a significant portion of domestic fossil fuel availability, it is appropriate to perform analyses using escalation rates greater than experienced in the past, and certainly greater than the "standard" expectations of only a few percent per year.

The effective and appropriate use of energy storage remains as an issue, even with a sellback path for excess energy generation. The point is that the sellback-only configuration requires the utility to accept the excess energy whenever it is available, not necessarily when it is needed. The result can be a degradation in generation efficiency and possibly the requirement for increased use of peaking units. Storage may provide special load management options not otherwise available.

Financial assumptions pertaining to the ownership of on-site units will have considerable effect on calculations of the cost of energy production. Utility companies have been reluctant to have a large number of small customer-owned systems connected to their grids and may themselves eventually own and operate on-site units. On the other hand utility attitudes appear to be changing and financing may be less expensive for individual owners than for a utility so that individually owned, controlled, and maintained units may become the norm.

There are several utility impact scenarios which can be defined for analysis. In the fixed utility scenario the conventional generating units are assumed to be prescribed and PV units are introduced. Calculations are then performed to examine the impacts. In an optimal utility scenario an optimum mix of conventional units is developed from a menu of possibilities to meet a given demand profile. PV units are then introduced and a new optimum mix is calculated using the same menu of conventional possibilities. The impact of PV penetration is inferred by comparing those two optimum configurations. In a transition utility scenario a prescribed mix of conventional units is assumed and new conventional and PV units are added consistent with a postulated growth in demand. The mix may not be optimal at any point in time because some of the units were selected at prior times when conditions were different.

2.0 IMPACTS ON OPTIMAL GENERATING MIX

In the analysis of the optimal utility scenario, the methodology adopted is a static incremental cost optimization formulation. In this methodology the demand is incorporated through standard load duration curves, and the optimization of the generating mix is calculated by superimposing the incremental cost of production curves for the various conventional generating units in the mix.

To discover the future-based cost of production characteristics of actual generating units, a menu of conventional power plants was compiled for projected 1990 costs expressed in 1980 dollars.

The corresponding cost of production curves were graphed and, with the lone exception of combined cycle generation, the crossover points of the various generating units are nearly coincident (Figure 2-1). The indication is that an optimal mix would

Figure 2-1. Annual Cost of Conventional Generation

consist almost entirely of combustion turbines and whichever baseload plants, coal and/or nuclear, are available. Also available from this analysis was the observation that, even with combined cycle plants in the mix, the highest crossover point is at only 0.32 capacity factor. In addition, oil thermal plants are precluded in an optimal mix with these data.

Using the load duration curve model for utility demand, the effects of photovoltaic penetration of the utility demand were introduced. The basic utility demand profile used is the projected Southern California Edison demand for 1990. The insolation data is based on Inyokern, California measurements taken in 1963. The change in the annual load duration curve for several PV penetration scenarios is shown in Figure 2-2.

For the utility studied, the April and December hourly load profiles exhibit an evening peak which is unmodified by the photovoltaic energy. However, for this utility the peak demand season occurs in summer due to cooling loads and this daytime peak is reduced by the photovoltaic source. The results support an argument for some capacity credit, but beyond a certain threshold of solar penetration the capacity requirement is determined by the secondary evening peak. It appears very likely that the amount of capacity credit to be accorded solar will be strongly utility dependent and this issue is still very much in controversy.

The incremental cost of production optimization and the calculation of the optimal capacity mix selected from the three types of conventional plants indicates that there are clear increases in combustion turbine utilization, and decreases in baseload coal utilization, as functions of increasing photovoltaic penetration, and that essentially all of the energy produced by photovoltaics displaces coal use in the optimal analysis scenario.

Interim observations and tentative conclusions based on the work include:

Incremental Cost Optimization Analysis

- As oil prices rise, oil plants, including combined cycle, become inappropriate in an economically optimum system mix.

Figure 2-2. Effect of Solar Penetration on Load Duration Curve

- The particular methodology used does not allow for study of the sensitivities of costs of production to oil price since the economic optimum precludes oil from the mix altogether.

PV Penetration Analysis

- Without storage or sellback large penetrations can impact baseload capacity and also reduce system peaks.
- Without storage but with perfect sellback there is a small impact on the optimum mix of conventional plants with a slight increase in cycling units.

3.0 IMPACTS ON PRODUCTION COST AND FUEL CONSUMPTION FOR A FIXED UTILITY

The purpose of this analysis is to investigate the impact of on-site photovoltaic units on an electric utility having a fixed conventional generation mix. The two figures of merit used in the study are fuel costs and fuel consumption, especially the reduction in oil usage. It is recognized that other utility costs such as investment in capacity, transmission, or distribution equipment, and operating costs such as maintenance, metering, or dispatching may also be impacted. However, the reduction in fuel costs and fuel consumption is believed to represent the most significant parameters characterizing the impact of on-site PV units.

The impact of on-site PV units was also examined in terms of a simplified utility rate structure. As noted above, one measure of PV impact is the resulting fuel cost reduction realized by the utility. The results of the fuel cost reduction analyses are integrated into a simplified rate model to determine an appropriate rate to be paid by the PV unit owner for backup electricity, and a rate to be paid by the utility to the homeowner for PV generated energy fed back into the utility grid.

A reference residential PV unit for use in the analysis was taken from a previous Aerospace study of optimum residential photovoltaic electric units. A limited number of parametric changes, such as varied array size and storage capacity, were examined from the perspective of the utility. The definition of the reference residence includes the house physical characteristics and demand profiles. Diversity among the

PV residences was represented in the analysis by varying individual house loads. The performance of the PV unit with respect to the site meteorology was simulated using the Aerospace developed computer program PVHOUSE, which provided the input to the utility system economic analyses.

The postulated utility is described using such characteristics as the location, types and sizes of plants and cost parameters. A single case which was analysed postulating an Arizona utility, was modelled after the broadly representative synthetic utility Scenario D developed by the Electric Power Research Institute (EPRI)(Ref. II-1). The sizes and types of power units included in the generating mix are noted in Table 3-1. This mix implies a fuel cost at the peak which is more than five times the baseload fuel cost as shown in Figure 3-1. Total utility system production cost impacts were assessed with a computer code which yields annual fuel costs, given the utility/load profiles, with and without on-site photovoltaic unit operation. Figures 3-2 through 3-5 illustrate the changes in the hourly load profiles for a typical case in which 100,000 PV residential units were postulated both with and without an energy storage capability at each house. Figures 3-6 and 3-7 indicate the resulting oil savings (other fuel savings are not shown) considering the several combinations in which energy storage is and is not included and also where a sellback provision is or is not (excess energy is then "dumped") provided. Figure 3-8 displays the impact on oil savings of various energy storage capacities.

A highly simplified residential rate model was postulated to examine the impact of varying PV penetrations on backup and sellback rates. This model assumes that the residential PV units are not credited with displacing conventional capacity or distribution system capital costs. It is also assumed that the capital costs attributed to the conventional capacity required to back up the PV units is allocated to the PV owner through a backup energy rate that is higher than the rate charged non PV owners but no distribution system capital costs are subtracted when calculating the rate to be paid by the utility for the excess energy (the sellback energy) sold to the utility, i.e., there is no "wheeling" charge. Figure 3-9 illustrates the backup and sellback rates expressed as a fraction of the rates applicable to a non PV residence.

Table 3-1. Fuel Cost and Efficiency Assumptions

Type of Fuel	Size, MW	Fuel Cost* (\$/Million Btu)	Heat Rate (Btu/kWh)	Fuel Cost (Mills/kWh)
Nuclear	1200	.885	1.044×10^4	9.2
Oil	800	3.62	9.155×10^3	33.1
	400	3.62	9.447×10^3	34.2
	200	3.62	9.979×10^3	36.1
Coal	600	1.31	8.989×10^3	11.8
	400	1.31	9.045×10^3	11.9
	200	1.31	9.576×10^3	12.5
Combustion Turbine	50	3.99	1.400×10^4	55.9

* 1985 Cost in terms of 1980 dollars

Figure 3-1. Utility Incremental Cost Curve

Figure 3-2. Demand and PV Output Profiles

Figure 3-3. Demand and PV Output Profiles

Figure 3-4. Demand and PV Output Profiles

Figure 3-5. Demand and PV Output Profiles

Figure 3-6. Oil Savings vs Number of PV Residences - No Storage

Figure 3-7. Oil Savings vs Number of PV Residences - On-Site Storage

Figure 3-8. Impact of Storage and Feedback on Oil Generation Savings

Figure 3-9. Backup and Sellback Rates vs PV Penetration - No Storage

The conclusions from this brief study, which are summarized below, must be viewed with an appropriate degree of caution. That is, the conclusions apply specifically to the boundary conditions, assumptions, and parameter values chosen and may vary for other locations, utilities, economic parameters and so on.

Oil Conservation

On-site photovoltaic units achieve oil conservation due to the gross energy displacement effect even though much of the generating capacity was coal or nuclear (Figures 3-6 and 3-7).

Storage and Sellback

Oil savings are impacted by both storage and sellback. In terms of oil conservation, more barrels of oil are saved when excess PV generated energy is fed back to the grid (Figures 3-6 and 3-7). This impact is enhanced when on-site storage is added (compare Figures 3-7 vs 3-8); however, beyond a critical value of storage capacity, the amount of oil conserved when energy is fed back decreases and approaches as a limit the amount conserved when excess PV energy is dumped (Figure 3-8). Similar trends are noted in terms of fuel cost savings. From the utility point of view, the net influence is a function of the storage efficiency, the prevailing prices for sellback and backup energy, and the alteration in the demand profile due to the particular storage logic employed. Storage and sellback tend to be counteractive in that the benefit due to their combination is less than the sum of their individual benefits.

Modelled Sellback and Backup Rates

The utility sellback rate decreases with increasing PV saturation, and also with array areas for the larger sizes, because the incremental excess energy displaces incrementally less valuable conventional fuel. The backup rate increases with increasing solar penetration, both array area and saturation, because the capacity factor of the conventional generators is thereby reduced resulting in less efficient utilization of the fixed capacity. The effect of energy storage is to further increase the backup energy rate and the sellback rate. The sellback rate decreases for very large array areas as the storage capacity increases.

Coupled Analysis Needed

The site owner and the utility company will often have opposing economic motives. Previous studies have concentrated on only one of the parties, with consequent loss of economic representation for the other. System acquisition decisions must involve coupled analyses in which the preferences and constraints of both groups are considered.

PART II. REFERENCE

- II-1. Synthetic Electric Utility Systems for Evaluating Advanced Technologies, EPRI EM-285, Electric Power Research Institute, Palo Alto, California, February 1977.

PART III. RATE STRUCTURES FOR ON-SITE PHOTOVOLTAIC UNITS

1.0 INTRODUCTION

The objective of this brief task was to assess current activities concerning rate structure studies, practices, rationales, and experiments as they affect the use of on-site photovoltaic power units.

2.0 FACTORS AFFECTING RATE STRUCTURE

Ownership: The rates which a utility will charge a customer, or pay a customer for electricity generated at the customer's residence is dependent upon ownership. If the utility owns the photovoltaic unit, the cost of power production will probably be treated as a supply of usable energy to the entire service area just as if it were produced at a central generating facility. If the customer owns the solar facility, however, the rate structure must consider the impact on utility capacity, requirements, capacity utilization, system operations, the time-of-day value of sellback energy, special interconnection and metering costs, and changes which occur as a result of increasing penetration of photovoltaics in the overall system. The utility rate base would not include the photovoltaic power production investment although the investment in distribution (excluding any interconnection equipment), transmission, capacity and general plant required to provide backup power would continue to be included in the rate base.

Solar System Characteristics: Since the utility generally bases its rate structure on energy use, capacity requirements, and operational efficiency*, the solar unit characteristics and output as well as the nature of the customer demand are both important to the determination of an appropriate rate structure. The nature of the insolation on an hour-by-hour basis relative to the load is important, as well as the amount of storage present in the photovoltaic unit.

* Most residential rates are highly simplified and do not explicitly identify these considerations. Operational efficiency refers to the use of a power factor related charge.

Utility Characteristics: The summer versus winter peaking characteristics of a utility could have a profound effect on the rate structures which are appropriate for photovoltaic systems. Another characteristic is the demand profile and weather sensitivity experienced by the utility and the aggregate size of the photovoltaic demand relative to the total load. Unit energy cost increases may occur from a need to use units that consume higher cost fuels per unit of energy output more frequently, to maintain larger spinning reserves, and to provide for special metering, status monitoring, maintenance, safety, or power quality provisions.

3.0 SURVEY SUMMARY

The analysis began with a survey of recent literature on rate structure development, especially those studies which address solar units. These included a number of time-of-day studies initiated by EPRI; documentation of special rates developed by utilities in anticipation of solar unit employment; ERDA and DOE-funded studies; and studies, policies, and regulations of various state and federal agencies. Several of the studies are summarized below (from Refs. III-1 to 8).

<u>Study Source</u>	<u>Relevant Contents</u>
Electric Power Research Institute (EPRI)	Time of use studies and experiments. Rates using marginal costs.
Johns Hopkins University	Review of field experiments for electrical rate design.
Feldman/Anderson	Assessment of ongoing activities in the interface between utility industry and solar energy for buildings. Recommendations related to pricing.
Office of Technical Assessments, DOE (OTA)	Recommended Federal Policies for promoting and regulating on-site solar energy.

Solar Energy Research Institute
(SERI)

Review of utility rate structures.
Effect of rates on solar unit economics.
Examples of proposed solar and wind rates.

ICF, Inc.

Impacts of alternate rate design for solar
space and water heating.
Impacts of solar on utility costs and prices.
Regulatory guidelines relevant to solar
power.

After the initial literature review, telephone interviews were held with four researchers active in the field of utility rates, four utilities, the California Public Utilities Commission (PUC), and EPRI. These interviews confirmed that there were few completed studies which were applicable directly to the problem of rate making for photovoltaic systems, but revealed that some were now underway.

4.0 EXISTING SOLAR RATE STRUCTURES

Solar Backup Power Rates: Sixteen utilities in twelve states have developed electric rates which are explicitly available to residential customers who own solar space and/or water heating units and who use electricity as a backup to these units. The rates include traditional declining block rates, energy charges varying with time of day, demand-energy rates, and controlled service tariffs. In most instances these rates are identical in structure and in level to those offered to all-electric customers. In a number of cases these rates have been incorporated to overcome exclusionary clauses. For example, some total electric schedules specify that electricity must be the primary or sole source of heating; a special rate or rider would be necessary for solar owners to be eligible for this tariff.

Parallel Generation Rates for Solar: Many states are now studying special rates with sellback provisions for on-site photovoltaic units and wind machines. States with such filings already adopted include California, Michigan, Montana, and New York. Some provide for an energy credit equal to the average cost of fuel per kWh, but impose a "demand" charge, either as a minimum or fixed value per kilowatt of capacity. One other rate schedule does not have a demand charge and provides energy credits which

are different for on-peak and off-peak usage. Another has no demand charge, and an energy credit equivalent to the energy charge except that the net energy cost cannot be negative. This rate implies a subsidy for the solar unit and does not appear to reflect the relative costs of service.

5.0 THE FUTURE OF SOLAR RATES

Most of the existing rate tariffs offered for solar are experimental in nature, and few residential customers have applied for these rates. Utilities and regulatory agencies are moving to have the rates in place before substantial penetration of solar occurs. As the market penetration of solar with sellback potential increases, the experimental rates will be converted to more permanent rates. Since these rates can be strongly affected by federal and state regulatory policies, it is important to examine these policies in detail in order to anticipate the new trends in rate making.

A comparison of the current solar rates with the rule making proposed by the Federal Energy Regulatory Commission (FERC) in response to the Public Utility Regulatory Policies Act (PURPA) (Ref. III-9) results in some significant discrepancies, since most of the current rates do not reflect the avoided costs to the utilities in their buy-back prices. The following represent areas recommended for further study: (1) continue to monitor public utility commissions and utilities as they respond to the FERC rule making, (2) continue impact studies to determine the aggregate effect of solar photovoltaic units on utilities in order to develop a quantitative understanding of costs avoided and additional costs incurred as a result of on-site power units with sellback which may be used as a basis for future rate making, (3) explore the effects of these new rate structures and the interconnection costs on market penetration of solar photovoltaic systems as a function of different regions and utility load types.

PART III. REFERENCES

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- III-8. Technical, Institutional and Economic Analysis of Alternative Electric Rate Designs and Related Regulatory Issues in Support of DOE Utility Conservation Programs and Policy, Volume I: Domestic Rate Survey, ICF Incorporated, Washington, DC., August 1978.
- III-9. Public Law 95-617, 95th Congress, Public Utility Regulatory Policies Act of 1978, November 1978.